National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Microwave Soundings in the Presence of Precipitation in the CPEX Experiment

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CPEX

Science Objectives

1. Improve understanding of convective processes including cloud dynamics, downdrafts, cold pools and thermodynamics during initiation, growth, and dissipation. Determine what combinations of environmental structure, including moist entropy budgets, and convective properties such as vertical velocity and reflectivity profiles, result in rapid upscale growth of a convective system into a large organized mesoscale convective system (MCS), or alternatively, result in failure to grow or rapid decay.
2. Obtain a comprehensive set of simultaneous wind, temperature, and moisture profiles, using wind lidar, microwave radiometer and sounder, and GPS dropsondes, conduct a quantitative evaluation of those profiles in the vicinity of scattered and organized deep convection, especially in the lowest 4 km, in all phases of the convective life cycle.
3. Improve model representation of convective and boundary layer processes over the tropical oceans using a cloud-resolving, fully coupled atmosphere-ocean model. Assimilate the wind, temperature and humidity profiles from the wind lidar and dropsondes into the model, and quantify the impact of these detailed lidar wind profiles on the ability of the model to simulate the life cycle of convective systems over tropical oceans.

https://cpex.jpl.nasa.gov

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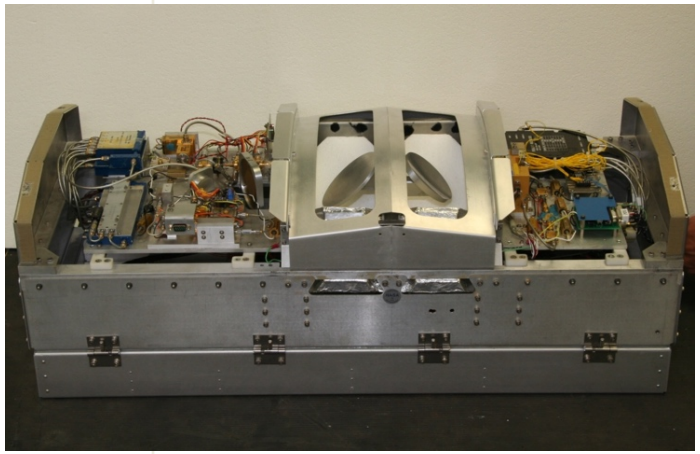
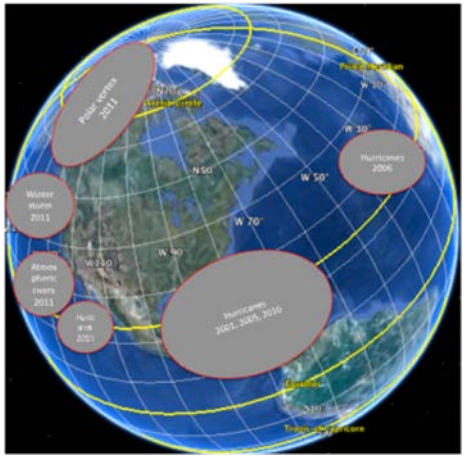
HAMSR Overview

High Altitude MMIC Sounding Radiometer

- Built under IIP-98 in 2001
- Pre-ATMS prototype
- Currently most accurate/sensitive MW sounder
  - Upgraded under AITT in 2010
- Flies on multiple platforms
  - Global Hawk
  - ER-2
  - DC-8
- Data transmitted from Global Hawk in R/T
  - Products displayed in R/T
  - V. useful for situational awareness



Now on the Global Hawk



Flown in many regions

Measurements

- Observations under all weather conditions
- Thermodynamic state of atmosphere
  - T(z), q(z), CLW
- Precipitation
- Convective structure
  - Reflectivity from hydrometeors
- Applications:
  - Hurricanes
  - Atmospheric rivers
  - Storms

Past and current campaigns

- CAMEX-4/Florida: Hurricanes **2001**
- TCSP/Costa Rica: Hurricanes **2005**
- NAMMA/Cape Verde: Hurricanes **2006**
- GRIP/California: Hurricanes **2010**
- WISPAR/California: **2011**
  - Atmospheric rivers
  - Pacific winter storms
  - Arctic science
- HS3/Virginia: Hurricanes **2011-2015**
- CalWater2/California: Atmospheric rivers **2015**
- SHOUT/CA, VA: Severe weather **2015-2016**
- CPEX **2017**

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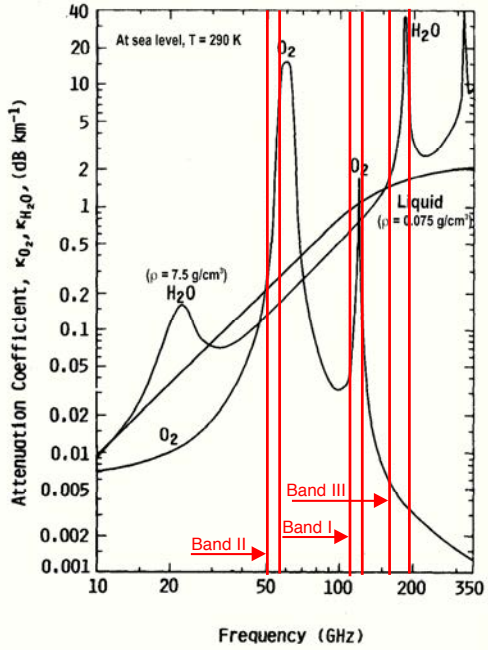
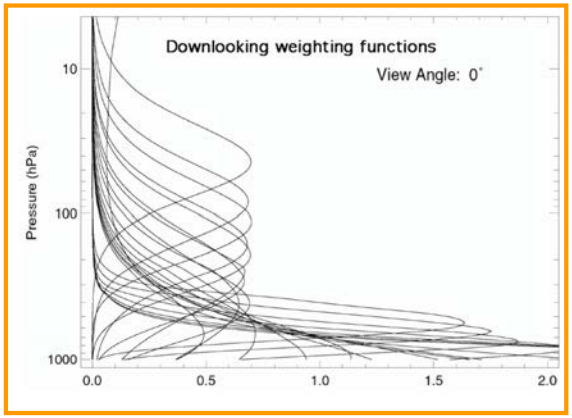
HAMSR Instrument Specs

HAMSR provides a 3D picture of the thermodynamic environment, convective structure & precipitation

Three spectral bands



Weighting functions



Direct measurements:

- **Brightness temperatures**
  - 25 channels
  - ~ 0.5 K cal. accuracy

Derived vertical profiles:

- Surface to aircraft altitude
- 1-2 km vertical resolution
- 1-2 km horizontal resolution
- Super-critical sampling

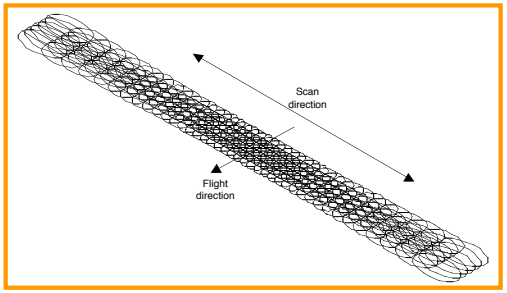
- **Temperature profiles**
  - Dual bands (50 & 118 GHz)
- **Water vapor profiles**
  - More accurate than AMSU-B
- **Liquid water profiles**
  - 3 bands ⇒ V. profile
- **Reflectivity profiles**
  - Experimental product

25 channels

Chan #	Center freq. [GHz]	Offset [GHz]	Bandwidth [MHz]	Wt-func. Peak [mb or mm]
I-1	118.75	-5.500	1500	Sfc/[30 mm]
I-2	"	-3.500	1000	Surface
I-3	"	-2.550	500	Surface
I-4	"	-2.050	500	1000 mb
I-5	"	-1.600	400	750 mb
I-6	"	-1.200	400	400 mb
I-7	"	±0.800	2x400	250 mb
I-8	"	±0.450	2x300	150 mb
I-9	"	±0.235	2x130	80 mb
I-10	"	±0.120	2x100	40 mb
II-1	50.30	0	180	Sfc/[100 mm]
II-2	51.76	0	400	Surface
II-3	52.80	0	400	1000 mb
II-4	53.596	±0.115	2x170	750 mb
II-5	54.40	0	400	400 mb
II-6	54.94	0	400	250 mb
II-7	55.50	0	330	150 mb
II-8	56.02 56.67	0	270 330	90 mb
III-1	183.31	-17.0	4000	[11 mm]
III-2	"	±10.0	2x3000	[6.8 mm]
III-3	"	±7.0	2x2000	[4.2 mm]
III-4	"	±4.5	2x2000	[2.4 mm]
III-5	"	±3.0	2x1000	[1.2 mm]
III-6	"	±1.8	2x1000	[0.6 mm]
III-7	"	±1.0	2x500	[0.3 mm]

⇒: Identical to AMSU ⇒: Equivalent to AMSU

Cross-track scanner



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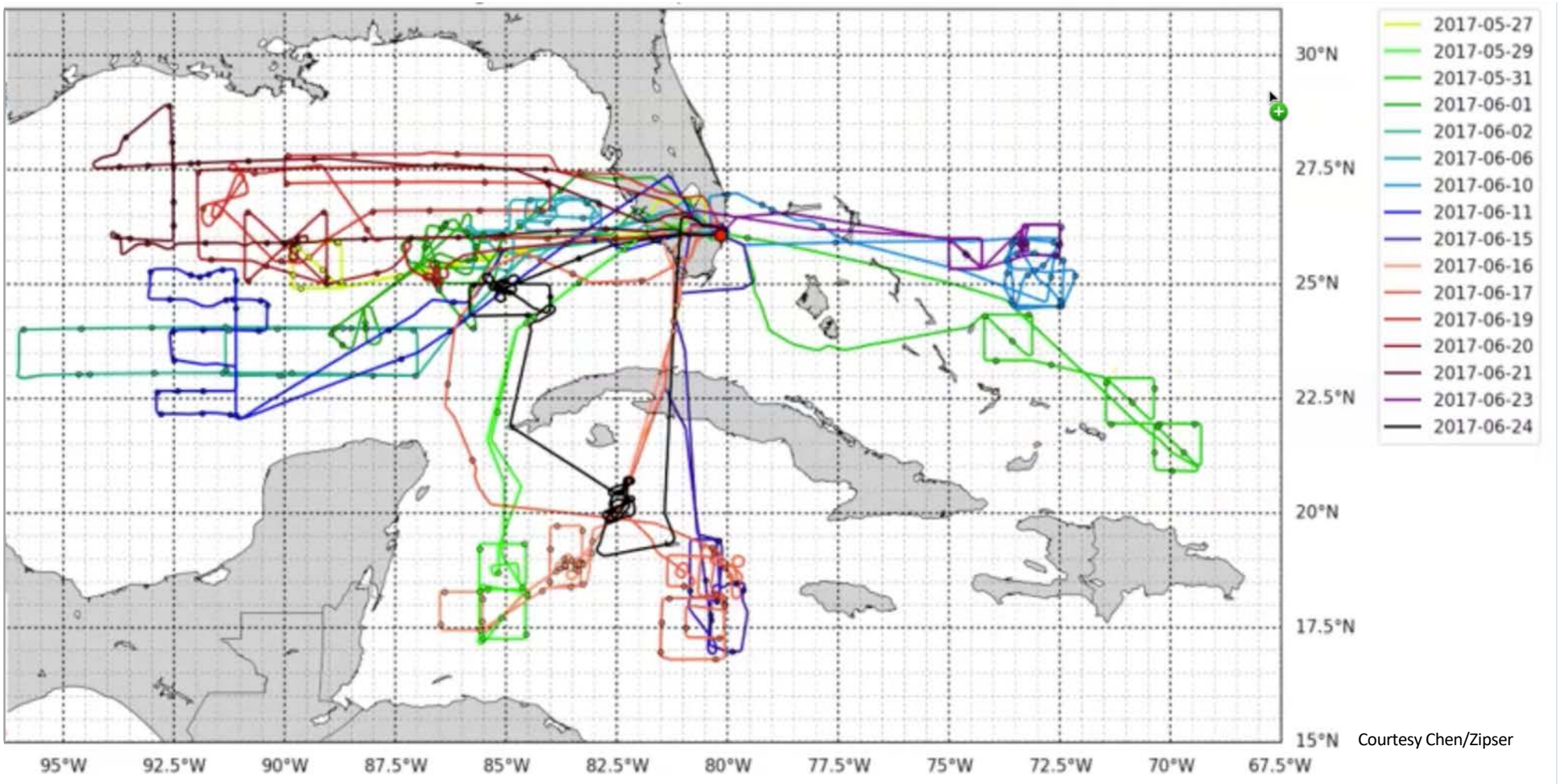
The CPEX Flights

16 flights, May 27 – June 24, 2017

1. Gulf of Mexico
2. Caribbean
3. Eastern N. Atlantic



Courtesy Chen/Zipser

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Microwave retrieval under scattering conditions

- We present an experimental microwave retrieval, based on optimal estimation
- The retrieval is different from most systems, because we are account for scattering, which allows us to retrieve information under rainy conditions
- We tested the retrieval on HAMSR data during CPEX campaign flights in 2017
- The following shows a few examples, mainly focusing on the day 2017/06/20, when we observed a tropical storm (Cindy)
- We show comparisons of our retrieval with regression approaches and dropsonde data
- The goal is to validate the retrievals and determine how far they are valid under precipitating conditions (error analysis, bias from observation)

RATATOUILLE

RATATOUILLE

Retrieval **A**lgorithm **T**estbed with **A** variety of **T**ransmutable **O**ptions to **U**nderstand **I**mpacts of **L**imiting components and **L**imitations from too high **E**xpectations

- Optimal estimation algorithm in development
- Uses CRTM
- Includes scattering, allows rain estimate
- Allows different background information (e.g. CYGNSS wind) for testing
- Allows channel selection (e.g. can eliminate 54.4 GHz after Flight #11)
- Gives uncertainty
- Algorithm testbed facilitated the development

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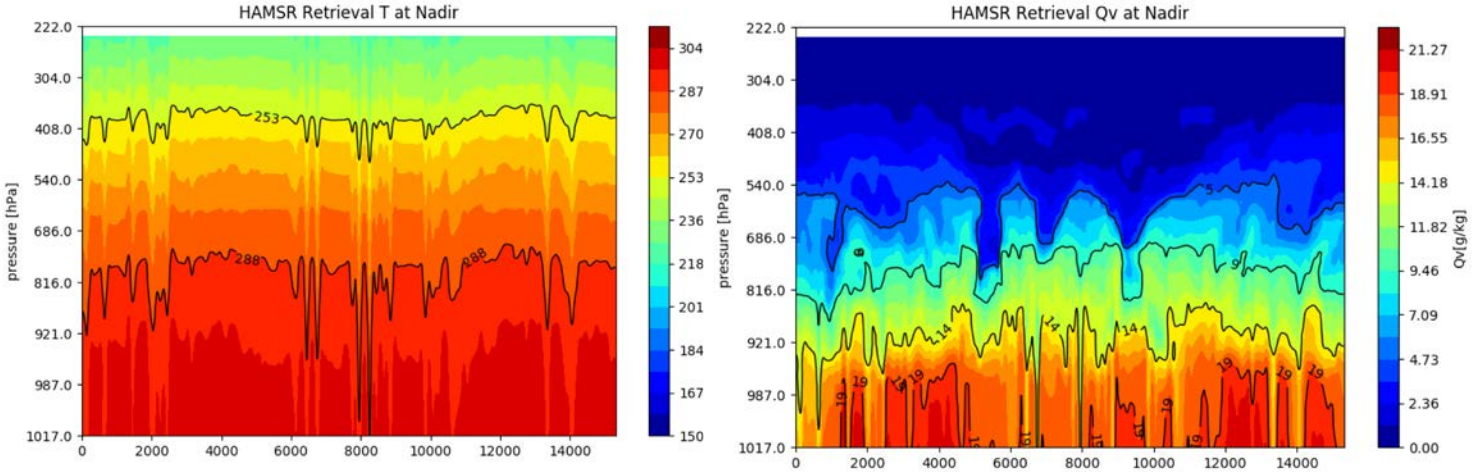
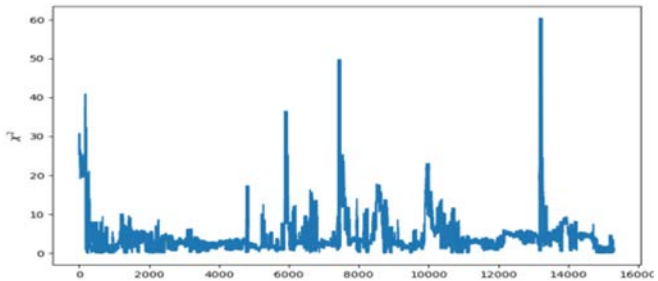
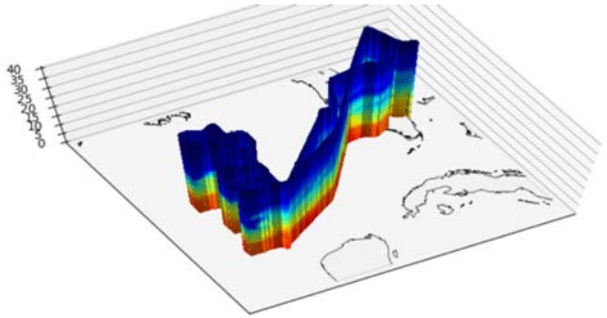
Example science flight

- Example for science flight #8 on June 19th:
  - Shown: temperature (curtain) and qv for nadir (curtain and 3d)
  - No gaps, still a little bit noisy
  - Areas with large uncertainty are identifiable via error estimate





Uncertainty estimate (chi-squared)



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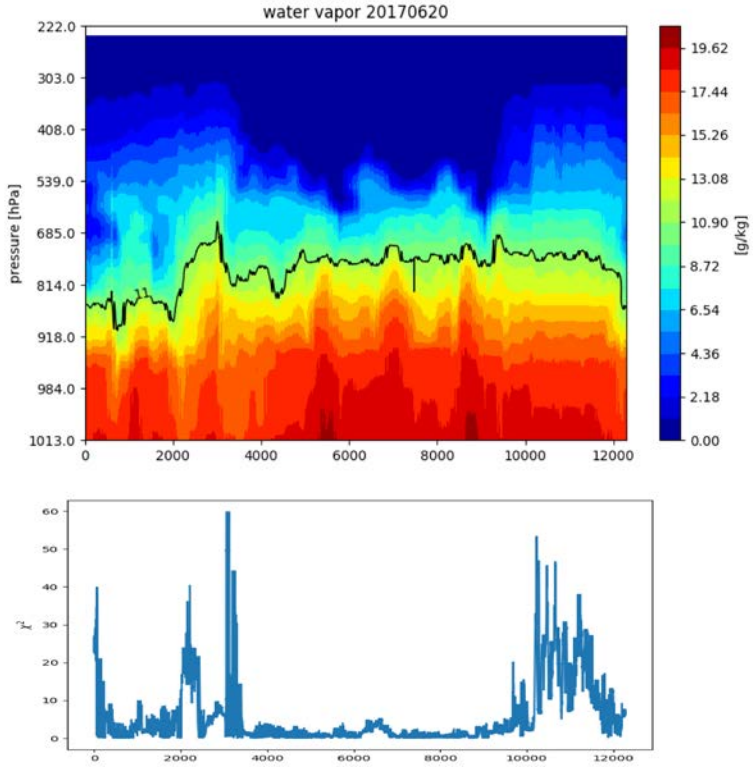
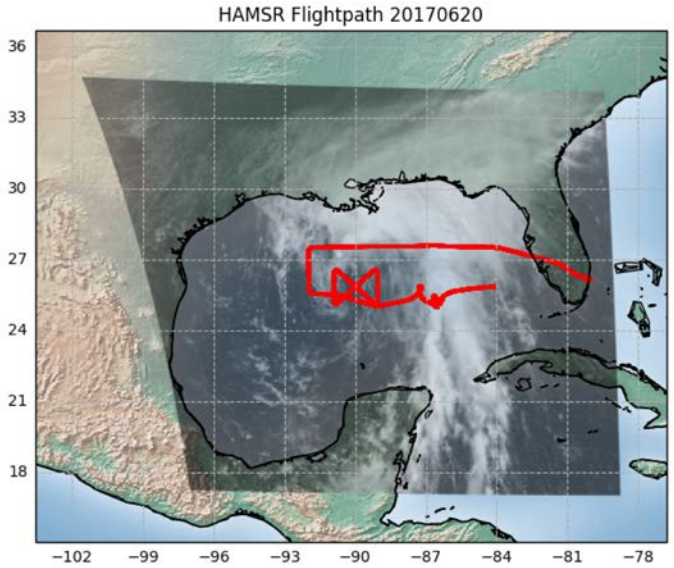
Rainy conditions, 6/20 - 1

Retrieval under rainy conditions:
Flight on 06/20/2017

- Flying around Tropical Storm Cindy
- Uncertainty estimates high during beginning and end



Uncertainty estimate



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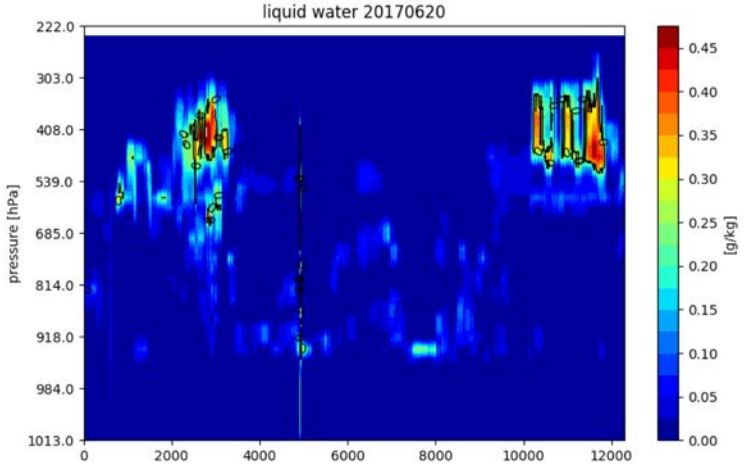
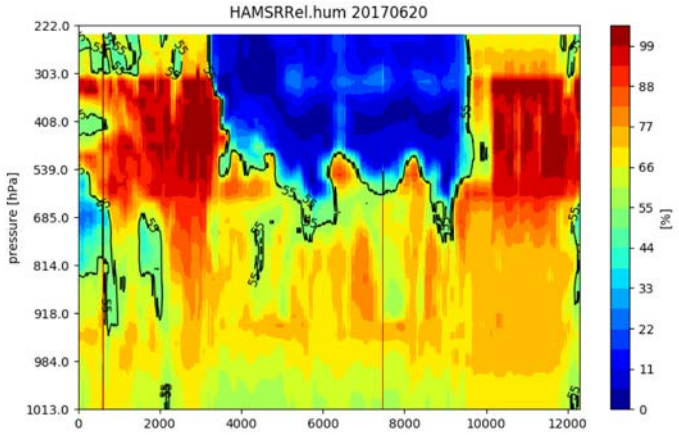
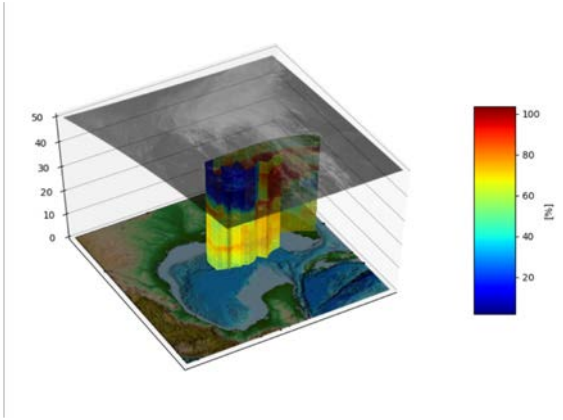
Rainy conditions, 6/20 - 2

Retrieval under rainy conditions: Flight on 06/20/2017

- Retrieved liquid water and relative humidity indicate strong convective systems during beginning and end of observations
- Overlapping with GOES cloud observations







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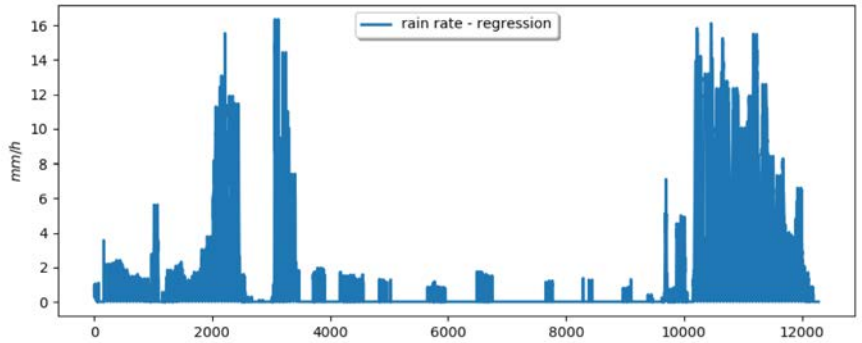
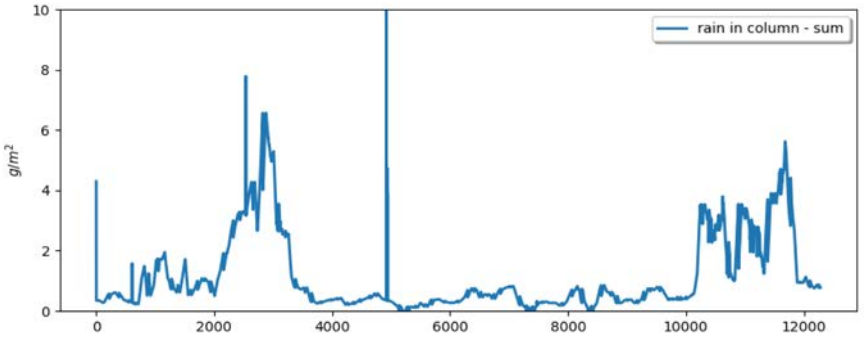
Rainy conditions, 6/20 - 3

Retrieval under rainy conditions: Flight on 06/20/2017

- We have two rain retrievals:
  - Rain regression, similar to Geo, Ferraro, Laviola, …
  - Based on optimal estimation, we get a "column rain" that can be converted to surface rain"
- Qualitatively, both show high rain rates at the same time we saw high liquid water and high relative humidity
- Quantitatively, we have usually less rain in the optimal estimation approach than in the regression





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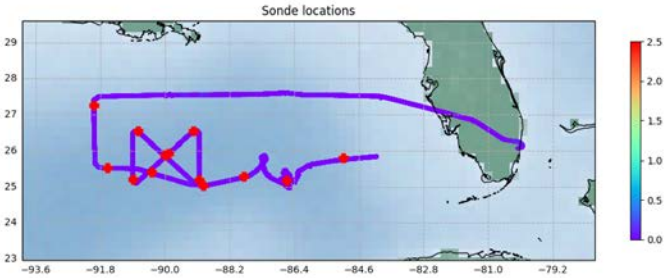
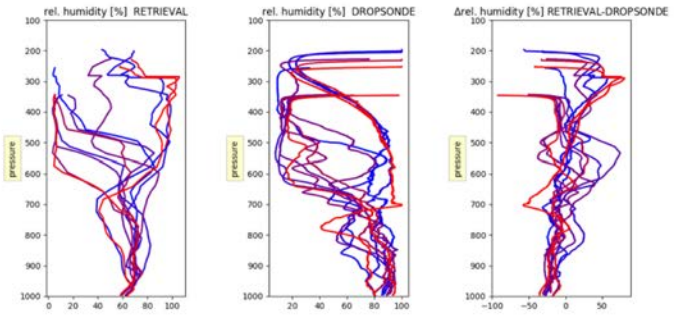
Rainy conditions, 6/20 - 4

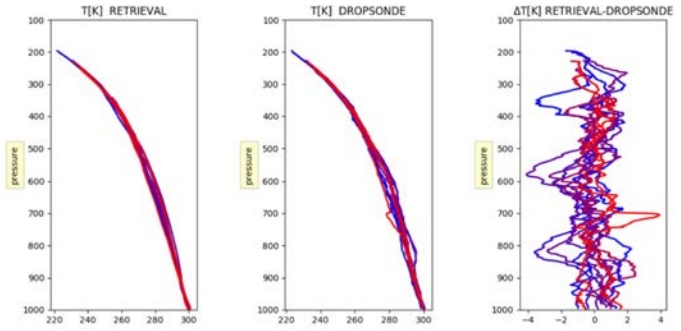
Retrieval under rainy conditions: Flight on 06/20/2017

"Validation" of the retrieval:

- We have around 16 dropsonde during this flight
- Several of them needed to be discarded or filtered to avoid unreasonable values – especially during the beginning of the drop (see plots below)
- It leaves us with 12 usable drop sondes, 4 of them under rainy conditions
- They are marked with red crosses







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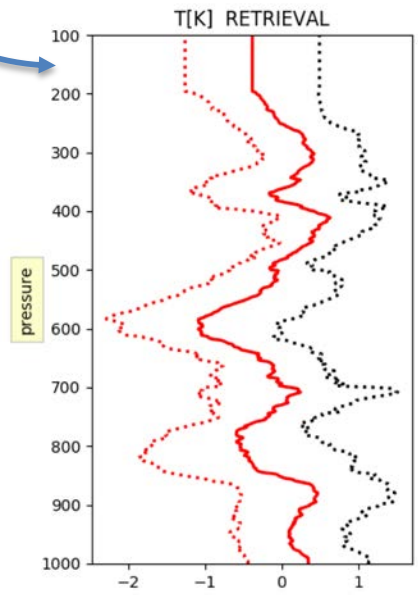
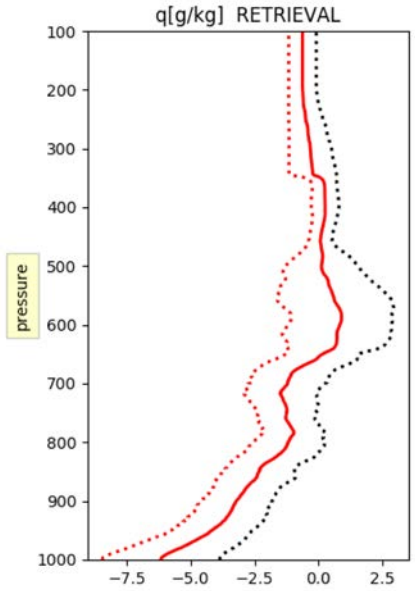
Rainy conditions, 6/20 - 5

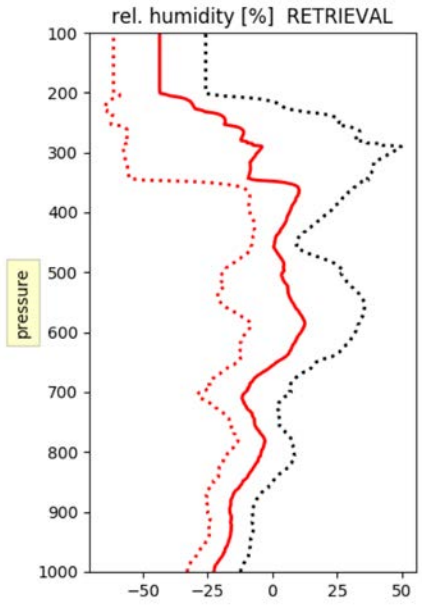
Retrieval under rainy conditions: Flight on 06/20/2017

- This comparison uses all usable sondes
- Overall, the temperature is captured well:
  - we have a slight higher temperature near the ground, but lower between 900 and 600 hpa
- The water vapor in the retrieval is dryer below 800hPa
- This is causing a lower relative humidity.

Note: Flight altitude was at 200 mb or lower, so profiles are not valid above that







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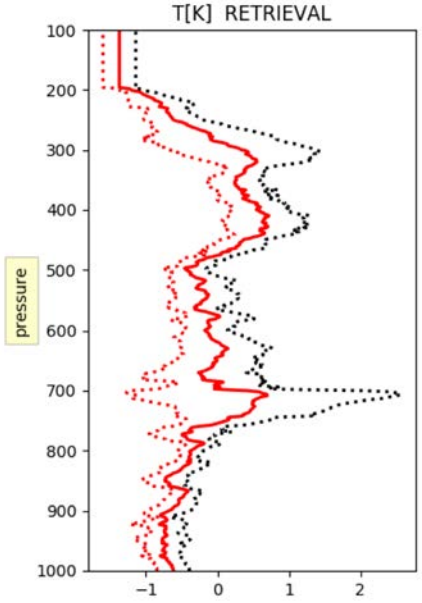
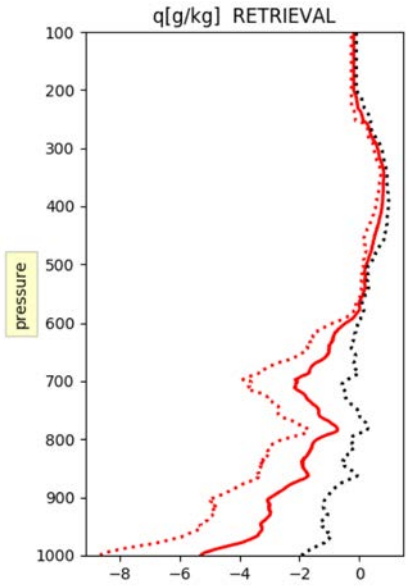
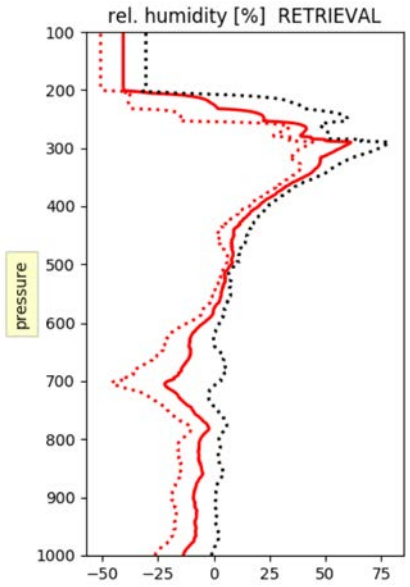
Rainy conditions, 6/20 - 6

Retrieval under rainy conditions: Flight on 06/20/2017

- This comparison uses the four “rainy” dropsondes
- Overall, the temperature is still ok:
  - we have a slightly lower temperature near the ground, and it is getting worse between 900 and 300 hpa
- The water vapor in the retrieval is dryer below 600hPa
- This is causing a lower relative humidity, whereas in the cloud, we have actually a higher relative humidity







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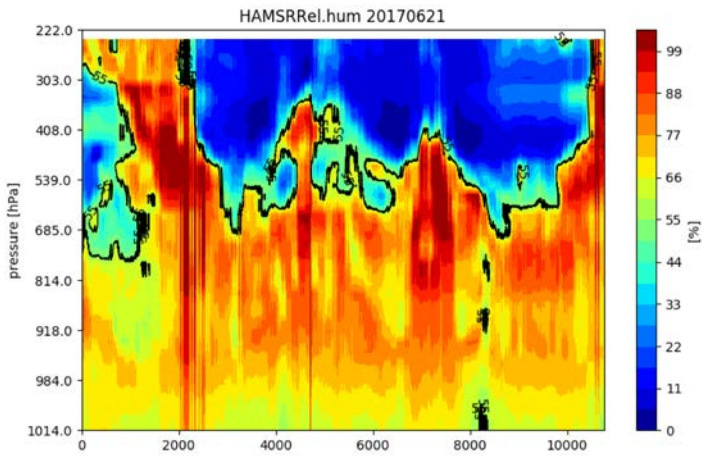
Light rain, 6/21 - 1

After the storm:
Retrieval under weaker rainy conditions:
Flight on 06/21/2017



- Flying through leftovers of Tropical Storm Cindy
- (NOAA GOES data could not be downloaded due to shutdown)
- Weaker convection

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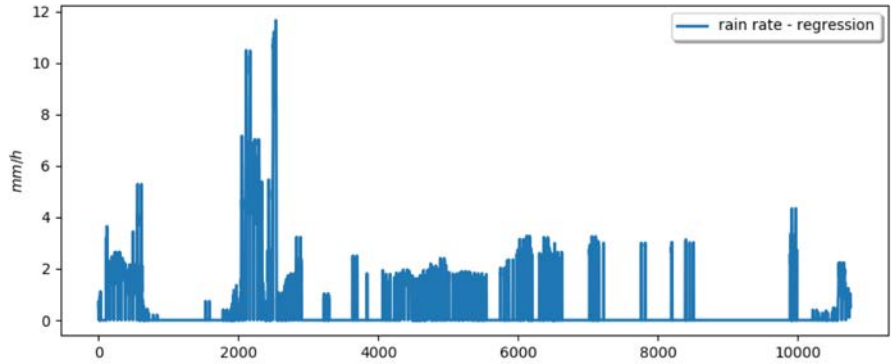
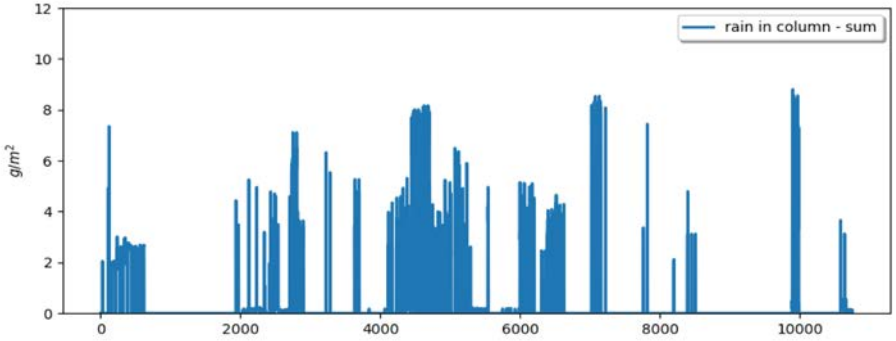
Light rain, 6/21 - 2

Flight on 06/21/2017

- We have two rain retrievals:
  - Rain regression, similar to Geo, Ferraro, Laviola, …
  - Based on optimal estimation, we get a "column rain" that can be converted to surface rain"
- Similar areas, but quite different magnitudes this time





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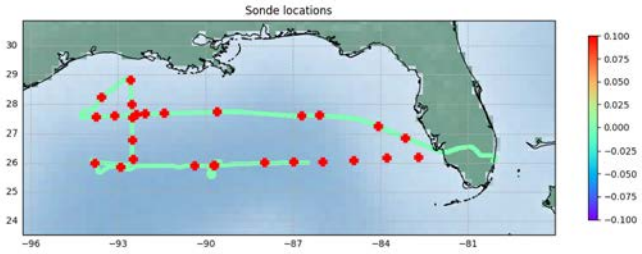
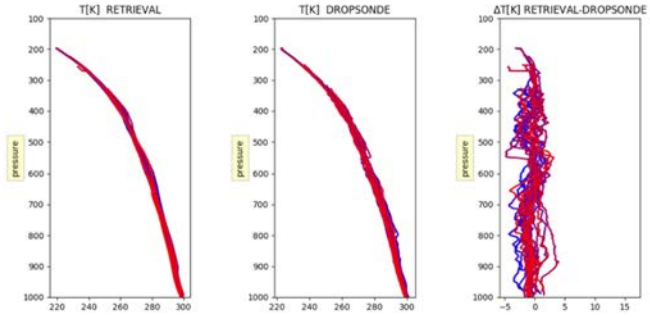
Validation, 6/21 - 1

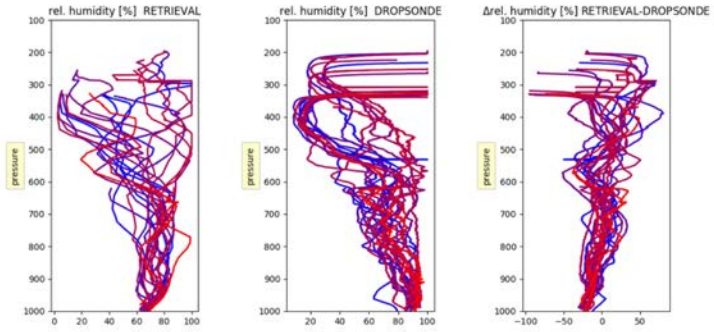
Flight on 06/21/2017



"Validation" of the retrieval:

- We have around 30 dropsonde during this flight
- After selection, we had ~ 25 usable drop sondes, 7 of them under rainy conditions
- They are marked with red crosses





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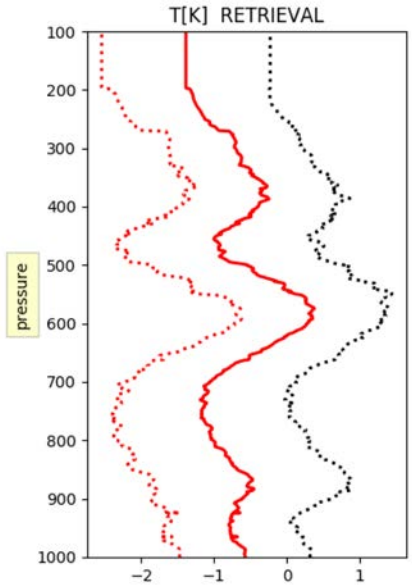
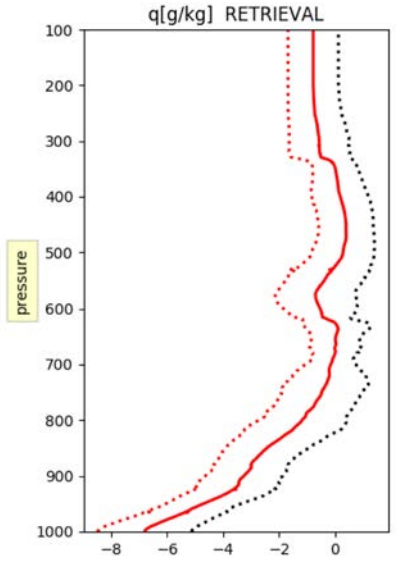
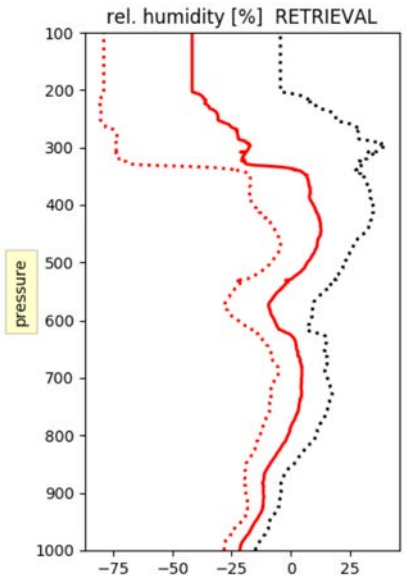
Validation, 6/21 - 2

All conditions:
Flight on 06/21/2017

- This comparison uses all usable sondes
- Overall, the temperature is captured well:
  - we have again a slight higher temperature near the ground, up to 600 hpa
- The water vapor in the retrieval is again dryer below 800hPa
- This is causing a lower relative humidity.







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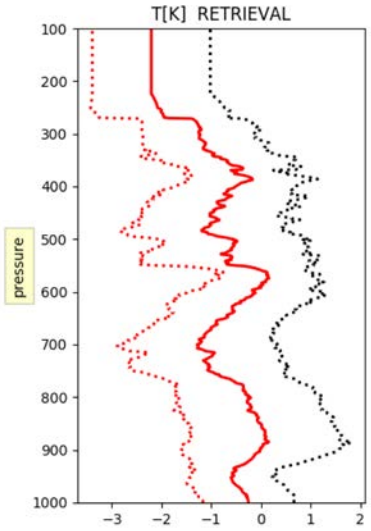
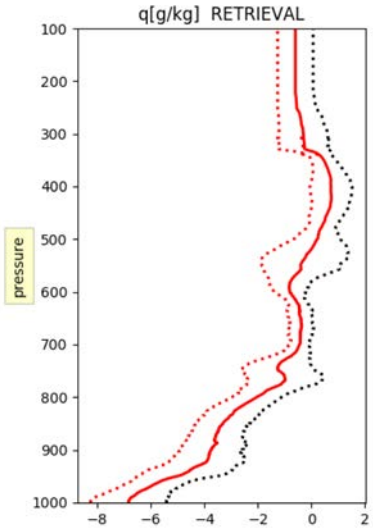
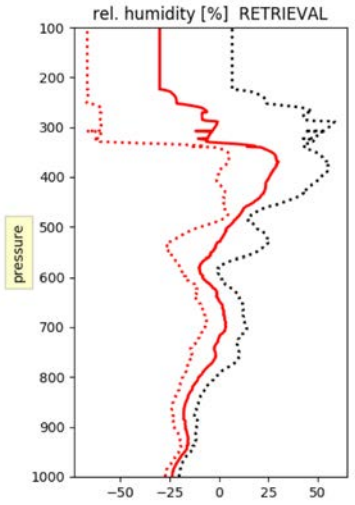
Validation, 6/21 - 3

Rainy conditions:
Flight on 06/21/2017

- This comparison uses the four “rainy” dropsondes
- Overall, the temperature is still ok:
  - we have a slight colder temperatures between 800 and 600 hPa
- The water vapor in the retrieval is still dryer below 600hPa
- This is causing a lower relative humidity, whereas in the cloud, we have actually a higher relative humidity







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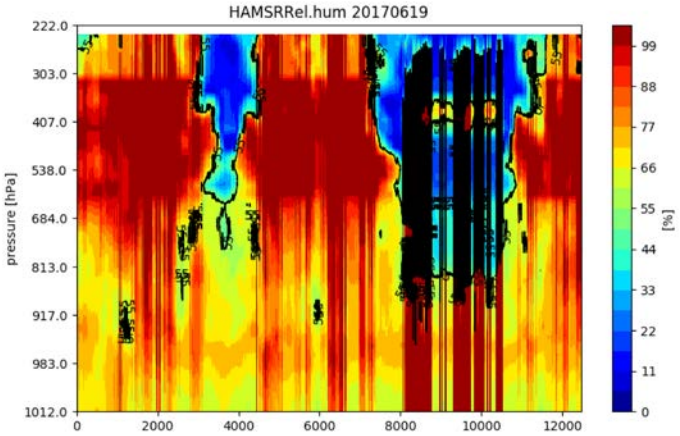
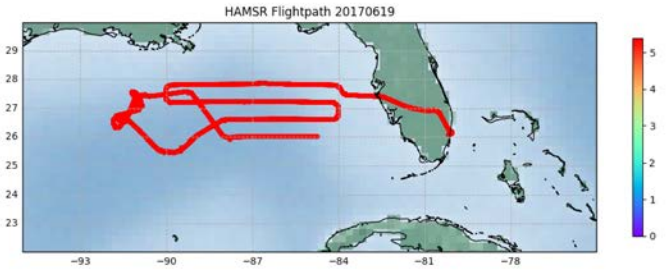
Rainy conditions, 6/19 - 1

Before the storm:
Retrieval under rainy conditions
Flight on 06/19/2017



- Flying through pre-Tropical Storm Cindy
- (NOAA GOES data could not be downloaded due to shutdown)
- Strong convection in the area
- HAMSR had some technical glitches (see stripes between 8000 and 11000)



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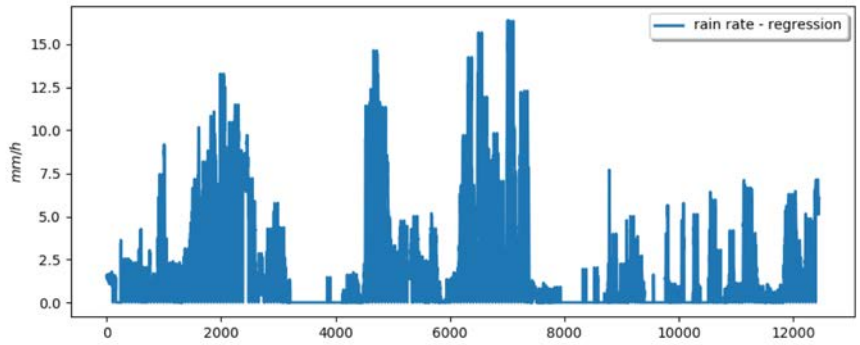
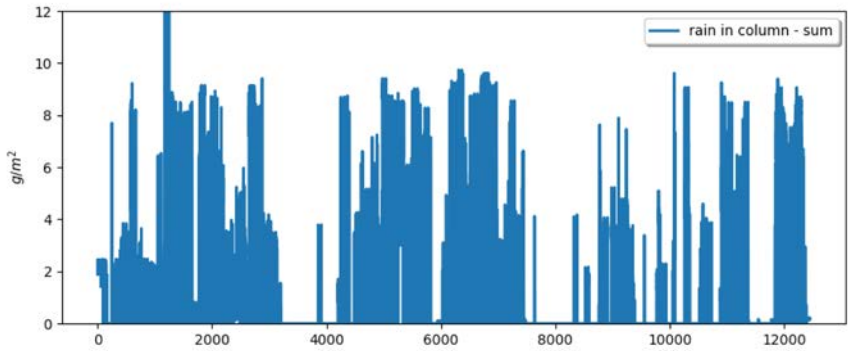
Rainy conditions, 6/19 - 2

Flight on 06/19/2017

- In general, it was a very rain day
- The regression tends to produce more rain in the beginning, whereas the optimal estimation has more rain in the end
  - This could be connected to instrument problems





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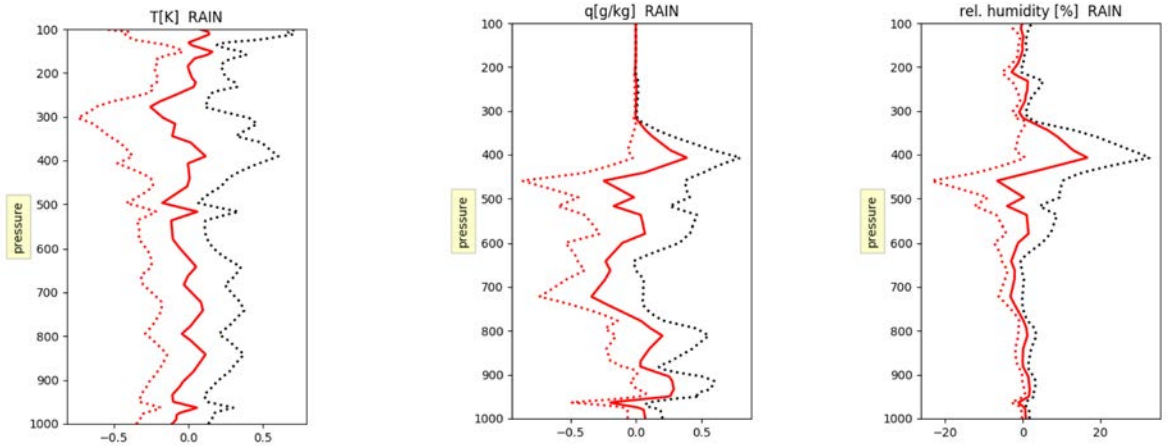
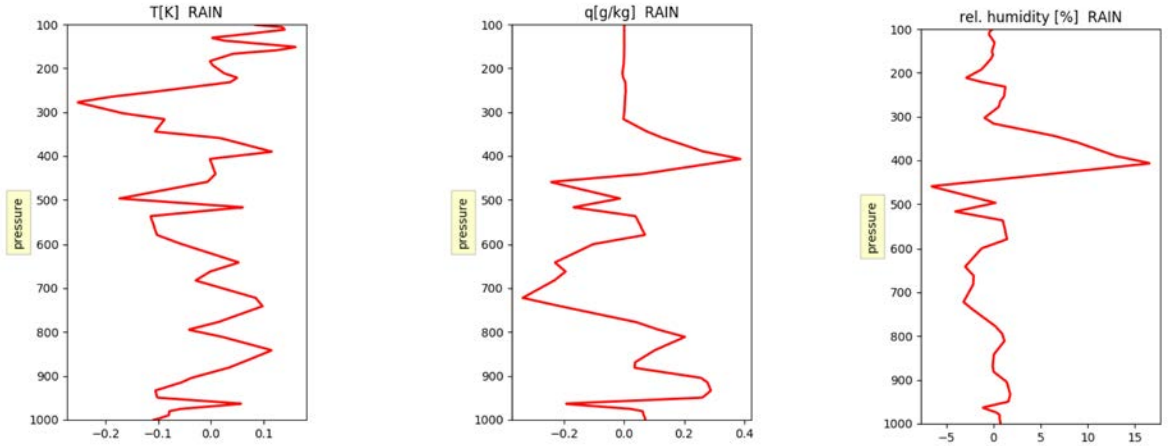
The effect of rain on the retrievals

Rainy retrievals vs non-rainy on 06/19

Differences between 100 randomly chosen profiles pairs within ~ 15 min:



Differences between means:



Rainy cases show a large increase in relative humidity near 400 mb

This is where the precipitating clouds are conentrated

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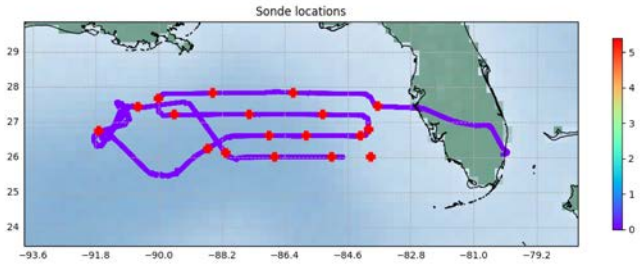
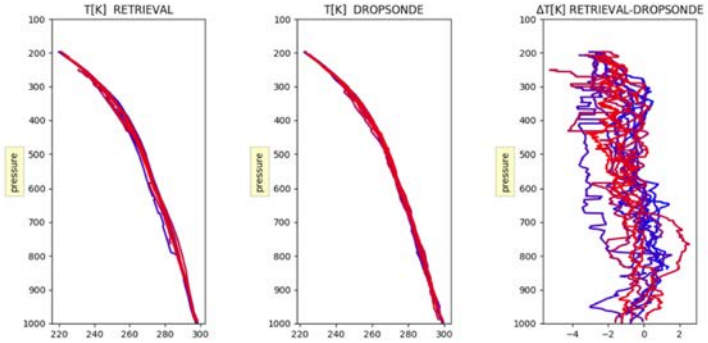
Validation, 6/19 - 1

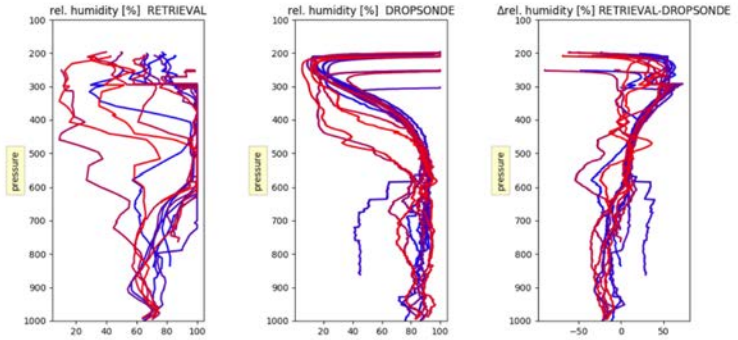
Flight on 06/19/2017

"Validation" of the retrieval:

- We have 19 dropsonde during this flight
- As HAMSR and sondes both had issues, we have ~ 15 comparisons left, not all of them reaching ground
- But: 10 of them are under rainy conditions!







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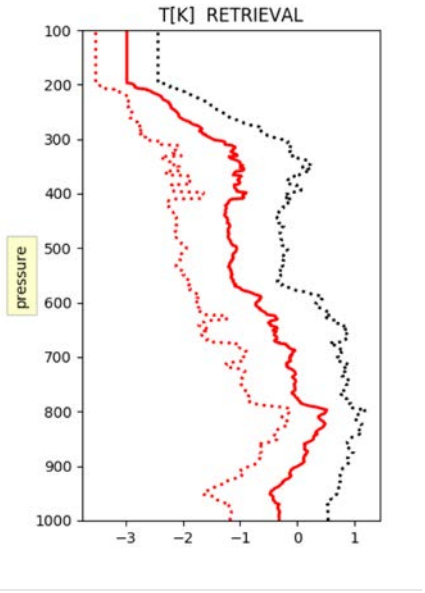
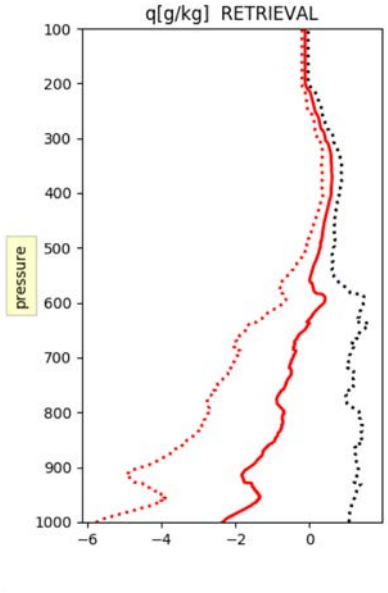
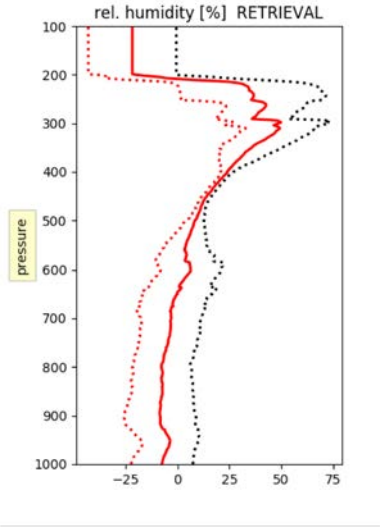
Validation, 6/19 - 2

Retrieval under rainy conditions: Flight on 06/19/2017

- This comparison uses all usable sondes
- Overall, the temperature is captured well:
  - But this time we have an increasing cold bias above 800 hPa
- The water vapor in the retrieval is still dryer below 800 hPa, but the magnitude is less than on 06/20 and 06/21
- The relative humidity is therefore better in the lower troposphere, but get's worse at higher altitudes







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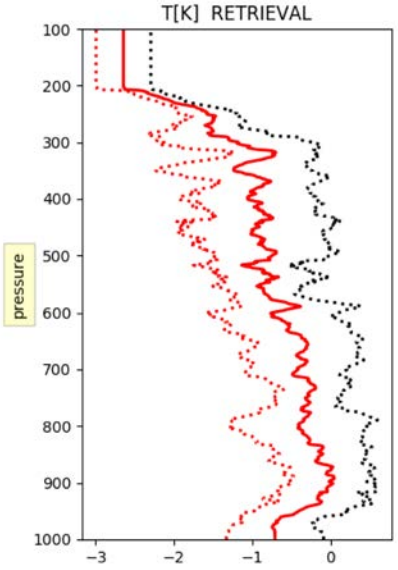
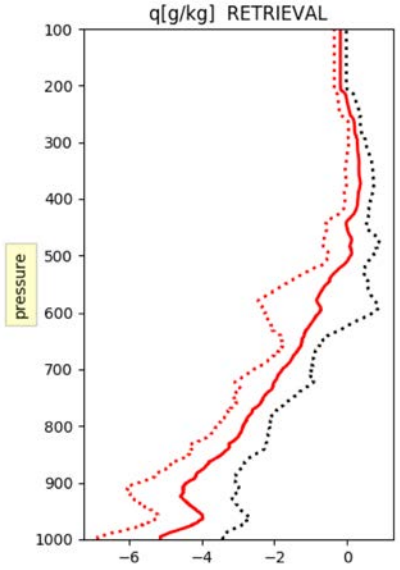
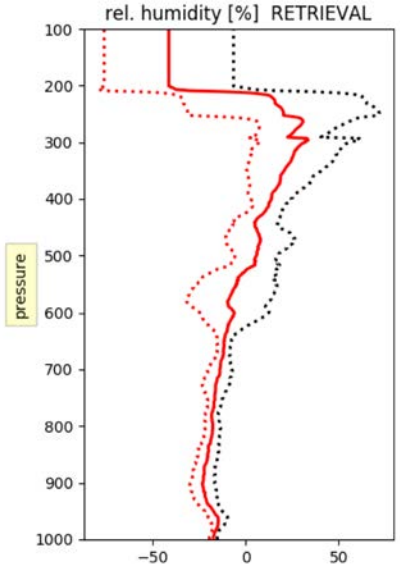
Clear validation, 6/19 - 3

Retrieval
under clear conditions:
Flight on 06/19/2017

- This comparison uses the four “non rainy” dropsondes
- The bias in the upper atmosphere is not so significant here
- However, water vapor shows a stronger negative bias again
- Which resulting in a more negative RH







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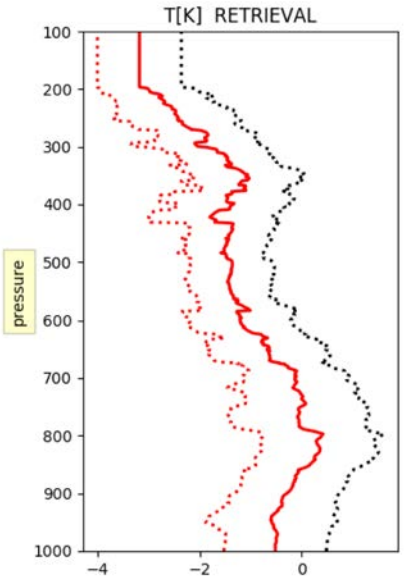
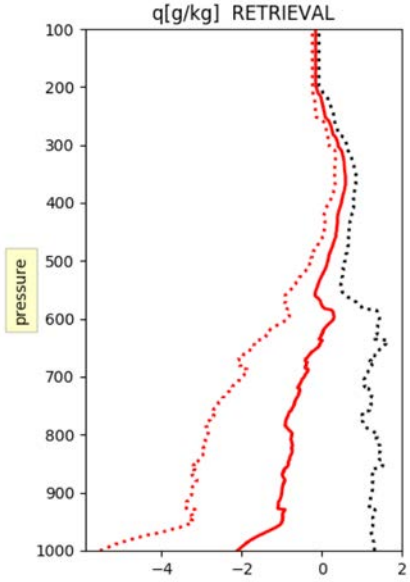
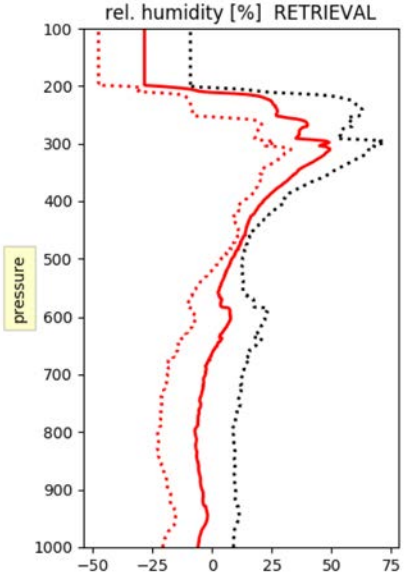
Validation, 6/19 - 4

Retrieval under rainy conditions: Flight on 06/19/2017

- This comparison uses the ten “rainy” dropsondes
- Overall pretty similar to before, as the majority of the sondes are under rainy conditions







Summary

- We presented an experimental microwave retrieval, which is based on optimal estimation and uses scattering to handle rainy conditions

- We tested the retrieval on HAMSR data during CPEX campaign flights in 2017

- Based on the results from the 2017/06/20 flight, we observe the following:

  - The uncertainty rapidlyincreases under precipitating conditions
  - The optimal estimation retrieval produces similar rain pattern as a regression, however it seems to produce less rain
  - Normally we have a slight positive bias in temperature retrievals near the surface, reversing to a negative one around 800 hPa
  - Under rainy conditions, we have a uniformly positive temperature bias
  - Our retrievals are dryer than the sonde below 800 hPa
    - Under rainy conditions, this can extend up to 600 hPa
  - The dry bias affects the relative humidity profiles, resulting in a negative bias
- Dropsondes might not be the perfect validation under rainy conditions, as they have problems of their own …

- Radar observations at the same time might help to validate the precipitation sum or column
  - Next step is to compare with APR-2 (CPEX) and IMERG (satellite)

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CPEX Data Portal

https://cpexportal.jpl.nasa.gov

- Displays NRT satellite data, model forecast, and airborne data products on a 3D global Earth using Cesium (a Google Earth-like web-based 3D Virtual Globe Platform).
- Overlays multiple types of products with opacity adjustment and separate calendars for model and data for easy comparison.
- Allows access to raw data associated with the images for interactive analysis. Subsetting tools are built in so users can select circular or rectangular areas, lines, or points on the globe.
  - MySQL and Solr databases are used to provide temporal and geospatial search to find the satellite swaths that intersect with the selected area.
- Supports data exploration and visual investigation of all the relevant data products that describe the physical processes in the CPEX domain before, during, and after the campaign.